METHOD AND APPARATUS FOR THE ACOUSTIC IMPROVEMENT OF THE PULSED CURRENT METHOD FOR CONTROLLING THE VELOCITY OF A TRANSDUCER HEAD

CROSS REFERENCE TO RELATED APPLICATIONS

Priority is claimed from U.S. Provisional Patent Application No. 60/211,332, filed June 9, 2000 entitled "Acoustic Improvement for the Pulsed Current Method of Actuator Velocity Control Based on Sampling VCM BEMF" and further identified as Attorney Docket No. 3123-362-PROV, which is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

The present invention relates to controlling the movement of an actuator arm in a computer disk drive. In particular, the present invention relates to improving the acoustic characteristics of a hard disk drive during loading and unloading of the actuator arm.

BACKGROUND OF THE INVENTION

Computer disk drives store information on magnetic disks in concentric tracks. A typical computer disk drive is illustrated in **Fig. 1**. The disk drive, generally identified by reference numeral **100,** includes a base **104** and magnetic disks **108** (only one of which is shown in **Fig. 1**). The magnetic disks **108** are interconnected to the base **104** by a spindle motor (not shown) mounted within or beneath the hub **112**, such that the disks **108** can be rotated relative to the base **104**. Actuator arm assemblies **116** (only one of which is shown in **Fig. 1**) are interconnected to the base **104** by a bearing **120**, such that the actuator arm assemblies **116** can be moved radially with respect to the magnetic disks **108**. The actuator arm assemblies **116** each include a transducer head **124** at a first end, to address each of the surfaces of the magnetic disks **108**. A

voice coil motor **128** pivots the actuator arm assemblies **116** about the bearing **120**, to radially position the transducer heads **124** across the surfaces of the magnetic disks **108**. The voice coil motor **128** is operated by a controller **132** that is in turn operatively connected to a host computer (not shown). By changing the radial position of the transducer heads **124** with respect to the magnetic disks **108**, the transducer heads **124** can access different tracks or cylinders **136** on the magnetic disks **108**.

The high rotational speed of the magnetic disks **108** when the disk drive **100** is in use creates a boundary layer of air that rotates with the surface of each disk **108**. This boundary layer is sufficient to suspend the transducer heads **124** above the surfaces of the disks **108** at a predetermined flying height. As the storage capacities of hard disk drives have increased, the flying height of the transducer heads **124** has become increasingly small. A low flying height assists in increasing the storage density of a drive **100** by allowing the magnetic transitions that store information on the disks **108** to be more tightly grouped. However, a low flying height requires a smooth disk surface, which results in increased friction between the transducer heads **124** and the surfaces of the disks **108** when the disks **108** are not rotating, thereby making it more difficult to bring the disks **108** to a rotational speed at which the heads **124** can fly. In certain instances, a "stiction event" can occur, in which the torque of the spindle motor is insufficient to break the adhesion between the transducer heads **124** and the surfaces of the disks **108**. In order to overcome these problems, disk drives have been provided with special “landing zones” having a textured surface and designed for receiving the transducer heads **124** when the disks **108** are not rotating. However, these textured areas can cause oscillations in low flying heads **124**. In addition, the provision of landing zones does not prevent actuator arms **116** from moving and

coming into contact with the disks **108**, for instance in response to shocks, and damaging the surfaces of the disks **108**.

In order to overcome these problems, disk drive actuator arm assemblies **116** may be provided with tabs or cam followers **138** capable of engaging corresponding cams **140** when the actuator arm assemblies **116** are in a parked position. The cams **140** each generally contain a ramp portion **144** and a detent portion **148**. When the disk drive **100** is not in use, the actuator arm assemblies **116** are generally positioned such that the tabs **136** are held in the cams **140** at the detents **148**. The transducer heads **124** are said to be "unloaded" from the disks **108** when the tabs **138** are held by the cams **140**. The terms "load" and "unload" can be interchanged, but for purposes of the present invention, "unloading" refers to removing a transducer head **124** from the disk **108** surface and "loading" refers to placing a transducer head **124** adjacent the disk **108** surface such that read and write operations may be carried out. When the transducer heads **124** are in the unloaded position, the magnetic disks **108** are protected from damage that may be caused by a collision between a transducer head **124** and the disk **108**, because the actuator arms **116** are held in place by the cams **140**.

Before data can be read from or written to the disks **108**, the transducer heads **124** must be "loaded" onto the surfaces of the magnetic disks **108**. In loading the transducer heads **124**, it is important to ensure that the transducer heads **124** are not traveling at too great a velocity. If the transducer heads **124** leave the cam **140** at too great a velocity, the component of their motion that is perpendicular to the surfaces of the disks **108** will likely be too great for the boundary layer of air to support the transducer heads **124** and prevent contact between the transducer heads **124** and the disks **108**. Such contact will likely cause a loss of data from the disk drive **100**.

Conversely, it is important to load the transducer heads **124** as quickly as possible, in order to limit the time period during which the host computer must wait before information can be retrieved from the disk drive **100**. Accordingly, it is desirable to closely regulate the velocity of the transducer heads **124** during loading. During unloading, high speed is also desirable. However, the transducer heads should not be unloaded at too great a speed, to avoid damaging the actuator arm assemblies when they contact the cams **140**. Also, if the head travels at too great a speed, it can bounce and strike the disk. In addition, cam wear is higher if the head travels at too great a velocity.

While the transducer heads **124** are being loaded, the transducer heads **124** are lifted away from the surfaces of the disks **108** by the cam **140**. Accordingly, information encoded on the disks **108** concerning the position of the transducer heads **124** with respect to the surfaces of the disks **108** is not available, and the velocity of a transducer head **124** cannot be determined by reading information from the disks **108**. However, the movement of the coils of the voice coil motor **128** with respect to the magnets of the voice coil motor **128** produces a back electromagnetic force (BEMF, or back EMF) in the coil of the voice coil motor **128**. Because this back EMF is proportional to the velocity of the actuator arm assemblies **116**, it can be sensed and used to determine the velocity of the transducer heads **124**.

The back EMF generated by the movement of the voice coil motor **128** can be determined if the resistance and inductance of the voice coil motor **128** are known. In particular, the back EMF generated by the movement of the voice coil motor **128** is equal to the voltage supplied to the voice coil motor less the voltage drop due to the internal resistance and inductance of the

voice coil motor. However, this method is unreliable, as the resistance of the voice coil motor **128** changes while the voice coil motor **128** is in motion.

Another approach to reading the back EMF generated in a voice coil motor **128** has been to turn off the drive current to the voice coil motor **128** at regular intervals of time. The back EMF is then sampled while the drive current is off. One such prior art approach is depicted in **Fig. 2**. In **Fig. 2**, a train of pulses **200** having regular pulse widths T_p **204** and varying current or voltage levels are shown. In between the pulses **200** are regular sampling intervals T_s **208**. During the sampling intervals, samples of the back EMF S_1, S_2, S_3, S_4 and S_5 are taken. According to this approach, the width T_p **204** of the pulses is constant, and the amplitude of the pulses **200** is varied in order to adjust the velocity of the transducer heads **124**. The provision of electrical power to the voice coil motor **128** is discontinued during the sampling times T_s **208** in order to allow an accurate reading of the back EMF to be taken. However, this approach results in the production of a relatively loud and objectionable audible noise due to the regular frequency with which power is applied to the voice coil motor **128**.

Another approach to controlling the velocity with which transducer heads **124** are loaded onto the surface of disks **108** is depicted in **Fig. 3**. According to this approach, pulses **300** having a first pulse width T_{p1} **304** and amplitude V_1 **308** are applied to the voice coil motor **128** in order to maintain a desired velocity of the transducer heads **124** with respect to the surfaces of the disks **108**. Where the velocity of the transducer heads **124** is too great, the pulses **300** are discontinued. After a predetermined number of pulses **300** having a first width T_{p1} **304** have been provided to the voice coil motor **128**, pulses **300** having a narrower width T_{p2} **312** are applied to the voice coil motor **128**. As with the wider pulses **300**, the pulses having a narrower width T_{p2}

312 are not provided if the velocity of the transducer heads **124** is found to be too high. Samples of the back EMF are taken at times S_1 to S_9, when no power is provided to the voice coil motor **128**. Accordingly, where the velocity of the transducer heads **124** is at or below a desired velocity, a train of pulses having a regular frequency is produced, thereby creating undesired acoustical noise. In addition, although the provision of pulses may be interrupted where the velocity of the transducer heads **124** is higher than a desired velocity, it is the velocity of the transducer heads **124** which determines whether the pulse train is interrupted or not. Accordingly, this approach does not reliably decrease acoustical noise produced during the loading and unloading of the transducer heads **124**.

It would be desirable to provide a method and apparatus for loading and unloading transducer heads **124** from the surfaces of magnetic disks **108** in such a way that an objectionable acoustical output is not produced. In addition, it would be desirable to provide such a method and apparatus that allowed accurate control of the velocity with which transducer heads **124** are loaded and unloaded from disk **108** surfaces. Furthermore, it would be desirable to provide such a method and apparatus that is inexpensive to implement and reliable in operation.

SUMMARY OF THE INVENTION

In accordance with the present invention, a method and apparatus for reducing the acoustic noise output of a computer disk drive when loading or unloading transducer heads is provided. The present invention generally provides pulses of electrical power to the voice coil motor used to load and unload the transducer heads that vary in time from one pulse to the next. By providing pulses of electrical power that vary in time, the spectrum of the acoustical output of

the disk drive is spread among a plurality of frequencies, thereby reducing the noise output of the disk drive.

In accordance with one embodiment of the present invention, a method and apparatus is provided in which the period of time during which electrical power is supplied to the voice coil motor is determined by reference to a table. In particular, a counter that is incremented with each pulse is used as an index to values stored in a table. Preferably, each succeeding table value differs from its predecessor, producing a noise spectrum that is distributed among a plurality of frequencies. Each of the time values stored in the table may be associated with proportioning values for use in connection with determining the output provided to the voice coil motor during each period. For instance, the associated proportioning values may be the inverse of the time value, ensuring that, when the transducer head is at a desired velocity, the total amount of power provided to the voice coil motor is the same regardless of pulse length.

Between each period during which power is supplied to the voice coil motor, a sampling interval is interposed. Toward the end of the sampling period, after the effects of the power supplied to the voice coil motor during the preceding power pulse have dissipated, a sample of the back electromotive force (BEMF or back EMF) is taken. The back EMF is measured as a voltage, and is proportional to the speed of the transducer head. Accordingly, the monitored back EMF is compared to a target voltage that corresponds to a target velocity.

In general, if the transducer head is not at the desired velocity, the voltage measured as the back EMF will not be equal to the target or desired voltage. Any discrepancy between the voltage measured as the back EMF and the desired voltage may be applied to the determination of the quantity of electrical power to be supplied during the succeeding pulse. In addition to a

proportional control term, the controller that supplies electrical power to the voice coil motor may include an integral term to account for the accumulated velocity error of the transducer head in determining the quantity of electrical power to be supplied to the voice coil motor during the next pulse. Furthermore, the controller may include a derivative control term.

According to another embodiment of the present invention, the time of each pulse of electrical power to the voice coil motor is determined randomly or pseudo-randomly. For instance, the period of time may be determined by a random or pseudo-random number generator. Preferably, the pulse widths resulting from the use of random or pseudo-random number generators are bounded by upper and lower time limits. The inverse of the "on" time or pulse width resulting from the use of a random or pseudo-random generator may be applied as a proportional term to the controller algorithm used to determine the total electrical or power output to the voice coil motor.

According to yet another embodiment of the present invention, the time periods during which power is supplied to the voice coil motor progress through a series of predetermined pulse widths. According to this embodiment of the present invention, the pulse times or widths may gradually increase as the controller progresses through the series, the pulse times may decrease as the controller progresses through the series, or each succeeding pulse time may simply be different from the preceding pulse time. The inverse of the pulse time may be provided to the controller as a proportional term.

Based on the foregoing summary, a number of salient features of the present invention are readily discerned. A method and apparatus for reducing the undesired acoustical output of a disk drive when loading and unloading an actuator arm are provided. The method and apparatus of

the present invention enable the times during which power is supplied to the disk drive to be varied, without regard to whether a monitored velocity of the transducer head is to be maintained or not. Therefore, a disk drive in accordance with the present invention ensures that the pulse width of a succeeding pulse differs from a preceding pulse, thereby spreading the acoustical energy over a wider range of frequencies. This in turn reduces the objectionable audible output from a disk drive during loading or unloading of the actuator arm assemblies.

Additional advantages of the present invention will become readily apparent from the following discussion, particularly when taken together with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagrammatic representation of a top view of a conventional computer disk drive, with the cover removed;

Fig. 2 is a diagrammatic representation of a pulse train having pulses produced at regular intervals according to the prior art;

Fig. 3 is a diagrammatic representation of a pulse train that provides pulses according to the velocity of the transducer head according to the prior art;

Fig. 4A is a diagrammatic representation of components of a voice coil motor control circuit in accordance with an embodiment of the present invention;

Fig. 4B is a diagrammatic representation of certain components of a voice coil motor;

Fig. 5 is a flowchart illustrating the operation of an embodiment of the present invention;

Fig. 6 is a diagrammatic representation of a pulse train produced according to an embodiment of the present invention;

Fig. 7A is a diagrammatic representation of a pulse train produced according to an embodiment of the present invention providing a varied output to the voice coil motor; and

Fig. 7B illustrates an example velocity of a transducer head in response to power inputs to the voice coil motor as illustrated in **Fig. 7A.**

DETAILED DESCRIPTION

Fig. 4A is a diagrammatic representation of components of a voice coil motor control circuit **400** in accordance with an embodiment of the present invention. The control circuit **400** generally includes an analog to digital converter **404**, a proportional-integral (PI) controller **408**, a voice coil motor driver **412** and the voice coil motor (VCM) **128**. In general, the analog to digital converter **404**, the proportional-integral controller **408** and the voice coil motor driver **412** may be provided as part of the controller **132**. The voice coil motor **128** includes a coil **416** (**Fig. 4B**) that is interconnected to an electrical power source (for instance the VCM driver **412**) and that can move through a magnetic field H produced by magnets **420**.

During a loading or unloading operation, the actuator arm assemblies **116** are moved by the voice coil motor **128** to position the transducer heads **124** above the surfaces of the disks **108**. The corresponding movement of the coil **416** of the voice coil motor **128** through the magnetic field H within the voice coil motor **128** produces a back electromotive force (BEMF or back EMF) in the coil of the voice coil motor **128**. According to one embodiment of the present invention, this back EMF, identified in **Fig. 4A** as signal **432**, is provided to the analog to digital converter **404**. As will be explained more fully below, the back EMF **432** is sampled by the analog to digital converter **404** while no power is being supplied to the coil **416** of the voice coil motor **128**, to increase the accuracy with which the back EMF **432** can be measured. The analog

to digital converter **404** generally compares the value of the back EMF **432,** which is a measured voltage, to a reference voltage. In general, because the back EMF **432** produced in the coil **416** of the voice coil motor **128** is proportional to the speed of the coil **416** through the magnetic field H of the voice coil motor **128**, the back EMF voltage can be correlated to a radial velocity of the transducer heads **124** across the disks **108**. Therefore, a reference voltage corresponding to a desired transducer head **124** velocity can be established. In general, the analog to digital converter **404** outputs a voltage signal **436** to the proportional-integral controller **408** that represents the velocity of the transducer heads **124**.

The proportional-integral controller **408** receives the velocity signal **436** and calculates a velocity error. The velocity error is equal to the difference between the voltage signal **436** and the reference voltage. In general, the velocity error is applied to the proportional-integral controller **408** control algorithm to determine the amount of power to be provided to the voice coil motor **128** during the next pulse. Although the use of a proportional-integral type control algorithm is preferred, it is not necessary. For instance, as will be appreciated by those of ordinary skill in the art, a proportional, proportional-derivative, proportional-integral-derivative, or any other control algorithm suitable for velocity control may be used.

The control signal **440** from the proportional-integral controller **408** is provided to the VCM driver **412**. The VCM driver **412** converts the control signal **440** to a power signal **444** that may be used to power the voice coil motor **128**. In particular, the VCM driver **412** may, where the control signal **440** is analog, comprise an amplifier. According to another embodiment of the present invention, the VCM driver **412** may comprise a digital to analog converter in combination with an amplifier. The power signal **444** produced by the VCM driver **412** is sent to

the coil **416** of the voice coil motor **128** to move the coil **416** with respect to the magnets **420** and to in turn move the actuator arm assemblies **116**.

With reference now to **Fig. 5**, the operation of an embodiment of the present invention is illustrated. Initially, at step **500** a count value N is initialized. According to one embodiment of the present invention, the initial value held by the counter is 0. At step **504**, the output of the proportional-integral controller **408** is set to an initial value I_i and is provided as a control signal **440** to the VCM driver **412**. At step **508**, the control signal **440** is amplified or converted to an analog signal and amplified by the VCM driver **412** and provided to the voice coil motor **128** as power signal **444**. As will be appreciated by those of ordinary skill in the art, the VCM driver **412** may be considered as either a voltage source or a current source. According to the present example, the duration or pulse width T_n of the initial output I_i may be determined by reference to a table as will be explained in detail below.

At step **512**, a check is made to determine whether the transducer head **124** has been loaded onto the disk **108** surface. This may be accomplished by determining whether valid position information is being read by the transducer head **124** from the disk **108**. If such signals are received, the transducer head **124** is loaded and the loading procedure ends (step **516**).

If it is determined that the transducer head **124** has not been loaded onto the disk **108**, the system delays for a sampling time period T_S after the previous power pulse has ended (step **520**). During the sampling period T_S the count N is incremented to the value N + 1 (step **524**). At step **528**, during the sampling period T_S, the back EMF is sampled. The velocity error may then be calculated (step **532**).

At step **536** the pulse duration or pulse width T_N corresponding to the count value N is determined. The time periods of the pulse duration or pulse width may be specified as absolute or relative times, or as a number of counts by a clock provided as part of the controller **132**. According to one embodiment of the present invention, the time T_N during which power is supplied to the voice coil motor is determined by using a counter as an index to a table of time periods. For instance, the least significant digit or a number of least significant digits of a counter may be referenced to a table of time values. For example, with reference now to **Table 1**, a value of N=0 corresponds to a time value of 5. As shown in **Table 1**, the time values are different for different values of N. **Table 1** illustrates a table containing four different time values or pulse widths. Accordingly, the table values may be conveniently accessed by use of a two bit counter, or by reference to the two least significant bits of a counter having more than two bits, to determine the value N and thus serve as an index to the time values in the table. Of course, greater or lesser numbers of time values may be used.

N	0	1	2	3
T_N	5	4	3	2
Kp_N	1/5	1/4	1/3	1/2

TABLE 1

According to another embodiment of the present invention, the pulse width T_N is determined randomly. Preferably, the randomly determined time period is constrained within lower and upper time bounds. According to this embodiment of the present invention, the time may be determined by a random or pseudo-random number generator.

According to still another embodiment of the present invention, the time T_N may be determined by rotating through a predetermined sequence of times. For instance, at time N=0, the pulse width T_0 may be equal to 2, at N=1 the pulse width T_1 may be equal to 4, T_2 may be equal to 8 and T_3 may be equal to 16. At N=4, the pulse width T_4 may again be equal to 2 and the time values may progress back through the sequence. Of course, any desired sequence of numbers may be used. In addition, although the described embodiments feature pulses that vary from one pulse to the next, this is not strictly necessary. For example, a relatively short train (*e.g.*, three or four pulses) of pulses having a first pulse width may be followed by another relatively short train of pulses having a second pulse width.

At step **540** the output I_N to the voice coil motor **128** is calculated. I_N may be calculated as a current or a voltage. According to one embodiment of the present invention, the calculation of I_N is performed in the proportional-integral controller **408** of the controller **132**, and the appropriate control signal **440** is provided to the VCM driver **412**. In general, the proportional term and any other terms of the control algorithm may be multiplied by a value Kp_N equal to the inverse of the pulse width T_N during which the output I_N is supplied to the voice coil motor (*i.e.,* the pulse width of I_N). The VCM driver **412** then provides a power signal **444** equal to the output I_N calculated at step **508**. Because of the multiplication of some or all of the terms of the control algorithm by the inverse of the pulse width T_N (*i.e.* by Kp_N), the control signal **440** may be proportioned such that, with all other factors being equal, the same total amount of power is supplied to the voice coil motor **128** during each pulse, even though the width T_N of each pulse varies. Accordingly, when the transducer head **124** is at the desired velocity, each pulse contains the same amount of power.

With reference now to **Fig. 6**, a pulse train **600** in accordance with an embodiment of the present invention is illustrated. The example pulse train **600** illustrated in **Fig. 6** may be generated using the values set forth in **Table 1**. Thus, when N is equal to 0, the pulse width T_0 is equal to 5 units. In addition, when N is equal to 0, the proportional term Kp_N, here Kp_0, is equal to 1/5. At N=1, T_1 equals 4 units and Kp_1 equals 1/4. Similarly, at N=2, T_2 equals 3 units and Kp_2 equals 1/3, and at N=3, T_3 equals 2 units and Kp_3 equals ½. It will be appreciated that the pulse width value T_N multiplied by the proportional term Kp_N is equal to 1 for any value of N. Accordingly, the power supplied to the voice coil motor **128** is normalized by the proportional term Kp_N, regardless of the pulse width T_N. Therefore, the pulse width or time T_N does not itself affect the total amount of power supplied to the voice coil motor **128** during a discrete pulse.

As mentioned above, the pulse train **600** comprises pulses having pulse lengths determined by the values set forth in **Table 1**. Furthermore, the pulse train **600** consists of pulses that each contain an equal quantity of power. In particular, the first pulse **604** of the pulse train **600** remains on for a pulse width or time T_0, here equal to 5 units. The first pulse **604** is followed by a sampling period T_S **606**. The back EMF is sampled during the sampling period T_S **606**, preferably at a point S_1 **612** that is towards the end of the sampling period **606**.

Referring to both **Fig. 5** and **Fig. 6**, after the back EMF has been sampled (step **528**), the velocity error of the transducer head **124** is calculated (step **532**). Next, T_N is determined (step **536**). As N is now equal to 1, reference to **Table 1** provides a value T_1 equal to 4 units and Kp_1 equal to 1/4. The output I_1 to the voice coil motor **128** is then calculated (step **540**). The second pulse **608** calculated at interval N=1 can be seen to have a higher output voltage than the previous pulse **604**. The second pulse **608** can also be seen to have a narrower width than the

first pulse **604**, as T_1=4 units. The total area of the second pulse **608** at interval N=1 is equal to the total area of the first pulse **604** at interval N=0. This is the expected output when the velocity error and any other inputs to the proportional-integral controller **408** remain unchanged. Of course, in operation, the amount of power in each pulse will typically vary due to the efforts of the controller **408** to maintain the transducer head **124** at the desired velocity.

As described above, if it is determined that the transducer head **124** has not yet been loaded (step **512**), the system again waits for a sample time T_S **606** (step **520**), during which time no power signal **444** is supplied to the voice coil motor **128**. Sample time T_S **606** may be a predetermined amount of time. In general, time T_S **606** is long enough to allow any voltage remaining in the coil **416** of the voice coil motor **128** due to the inductance of the coil **416** to dissipate before the back EMF **432** in the coil **416** is sampled. Accordingly, towards the end of the time T_S **606**, at point S_2 **616**, the back EMF **432** is sampled (step **528**).

In the example illustrated in **Fig. 6**, it is assumed that the proportional-integral controller **408** receives a velocity error signal **436** such that it directs each pulse in the pulse train **600** to provide the same total amount of power to the voice coil motor **128**. Accordingly, the third pulse **612** has a pulse width T_2 of 3 units, but the total area of the third pulse **612** is equal to the areas of each of the preceding pulses **604** and **608**. The fourth pulse **616** has a pulse width T_3 equal to 2 units, but a higher output than any of the preceding pulses **604, 608** and **612**. In particular, the area of the pulse **616** is equal to the area of each of the pulses **604, 608** and **612**.

In the illustrated example, which receives pulse widths T_N from **Table 1**, N is determined by a two bit counter. Therefore, incrementing the counter from N=3 results in a value of N=0, and the pattern of pulses having widths of 5, 4, 3 and 2 units respectively is repeated. In this

way, a pulse train is supplied to the voice coil motor **128** that produces an acoustical output that comprises at least four major frequencies, and the amplitude of that output is divided among the four frequencies. This is in contrast to a conventional pulse train used for controlling a voice coil motor **128** during loading and unloading operations, which produces an audible output concentrated at one frequency. Accordingly, the acoustical output produced by a pulse train **600** in accordance with the present invention has a volume that is lower at any particular frequency, and is less objectionable than a pulse train having a series of pulses that are identical in their duration.

With reference now to **Figs. 7A** and **7B**, aspects of the operation of an embodiment of the present invention are illustrated. In particular, **Fig. 7A** illustrates a pulse train **700** provided as a power signal **444** to a voice coil motor **128**. The trace **704** in **Fig. 7B** illustrates the velocity of the transducer head **124** with respect to the disk **108** in response the pulse train **700** shown in **Fig. 7A**.

In general, the pulses comprising the pulse train **700** have one of four possible widths. In particular, the pulse widths may be determined using a counter as an index to a table (*e.g.* **Table 1**) of pulse widths and corresponding proportioning values. Accordingly, the assignment of pulse widths and proportioning values to a particular pulse may be carried out as described above with respect to the pulse train **600** illustrated in **Fig. 6**. Initially, at time 0, a first pulse **708** having a duration or width of five units is supplied as a power signal **444** to the voice coil motor **128**. In response to the first pulse **708**, the velocity of the transducer head **124** can be seen to accelerate in **Fig. 7B**. At time A, after the pulse **708** has ended, the velocity of the transducer head **124** can be seen to decelerate slightly, for instance due to friction. At point S_1**710**, the back EMF in the

voice coil motor **128** is sampled. Accordingly, at point S_1 **710**, the controller **132** is provided with information concerning the velocity of the transducer head **124**. Because at point S_1 **710** the velocity as shown by trace **704** is less than a target velocity **712**, it is determined that more power should be supplied to the voice coil motor **128**.

According to one embodiment of the present invention, the proportional-integral controller **408** determines the power signal **444** to be applied to the voice coil motor **128** according to an algorithm that includes both proportional and integral terms. In particular, according to one embodiment of the present invention, the power signal **444** is given by the equation $I=Kp_n*BEMFerror_n+Nulli_n$, where $Nulli_{n+1}=Nulli_n+Ki*Kp_n*BEMFerror_n$, and where Kp_n is a proportional term, K_i is an integral term, $Nulli_n$ is the integrator value, and $BEMFerror_n$ is the difference between the measured back EMF and the reference voltage corresponding to the desired transducer head **124** velocity. As described above, Kp_n may be inversely proportional to the pulse length of T_n. According to one embodiment of the present invention, K_i is a fractional value.

The second pulse **716** has a width of 4 units. However, the total area, and thus the total amount of power provided by the second pulse **716**, is greater than the total area of the first pulse **708**. In response to the second pulse **716**, the trace **704** of the velocity of the transducer head **124** can be seen to increase. At point S_2 **718**, a sample of the back EMF **422** in the voice coil motor **128** is again taken. The controller **132** receives this information and determines that the velocity of the transducer head **124** has moved closer to the target velocity **712**, but is still below the target velocity **712**. Accordingly, the third pulse **720**, which has a time equal to 3 units, is provided having a total area slightly less than the total area of the preceding pulse **716**. At point

S_3 **722**, a sample of the back EMF is again taken, and it is determined that the velocity of the transducer head **124** exceeds the target velocity **712**. Accordingly, the fourth pulse **724**, which has a width of 2 units, has an area less than the total area of the preceding pulse **720**.

At point S_4 **726** it is determined that the velocity of the transducer head **124** remains above the target velocity **712**. Accordingly, although the fifth pulse **728** has a width of 5 units, the total area of the fifth pulse **728** is much less than any of the preceding pulses, in order to bring the velocity of the transducer head **124** closer to the target velocity **712**. In addition to the influence of the velocity detected at point S_4 **726**, which is greater than the target velocity **712**, the electrical power supplied by the fifth pulse **728** is reduced as compared to the previous pulses **708**, **716**, **720** and **724** due to the effects of the integral term of the proportional-integral controller **408**, which accounts for accumulated velocity errors. At point S_5 **730** a sixth pulse **732** is provided having a width of 4 units and slightly more area than the fifth pulse **728**, as the velocity of the transducer head **124** is about equal to the target velocity **712**.

Of course, the particular amounts of power provided by individual pulses in a pulse train such as the pulse train **700** illustrated in **Fig. 7A** will vary depending on the particular algorithm implemented by the proportional-integral controller **408**. However, it should be appreciated that, according to the embodiment of the present invention described in connection with **Figs. 7A** and **7B**, each pulse in a pulse train produced in accordance with that embodiment has a width that is different from the width of the preceding pulse. According to other embodiments, each pulse need not have a width that differs from the preceding pulse. For instance, a train of two or more pulses having a first width may be followed by a train of two or more pulses of a second width.

In the discussion set forth herein, the pulse widths have been described in terms of "units". It will be appreciated that the pulse times selected for a particular application may be determined for that application. In addition, it will be appreciated that the particular pulse widths selected are not important, so long as the width of a pulse at any point in time is different from the preceding pulse. According to one embodiment of the present invention, four different pulse widths ($T_1 = 400\ \mu s$, $T_2 = 1000\ \mu s$, $T_3 = 600\ \mu s$ and $T_4 = 800\ \mu s$) are used. However, the number of different pulse widths and the values of the pulse widths may be adjusted to suit the particular application.

In the preceding examples and discussion, the loading of a transducer head **124** onto the surface of a disk **108** has been described. However, the present invention is equally applicable to the unloading of a transducer head **124** from a disk **108**. In particular, the present invention reduces the acoustical output of a disk drive **100** during the unloading of a transducer head **124** by providing a train of pulses having varying widths. However, instead of detecting position signals derived from the surface of a disk **108** to indicate that a transducer head **124** has been loaded, during unloading, reaching a maximum current for several samples in a row, without reaching a target velocity, may be used to indicate that a transducer head has properly engaged a corresponding cam **140**.

The foregoing discussion of the invention has been presented for purposes of illustration and description. Further, the description is not intended to limit the invention to the form disclosed herein. Consequently, variations and modifications commensurate with the above teachings, within the skill and knowledge of the relevant art, are within the scope of the present invention. The embodiments described hereinabove are further intended to explain the best

mode presently known of practicing the invention and to enable others skilled in the art to utilize the invention in such or in other embodiments and with various modifications required by their particular application or use of the invention. It is intended that the appended claims be construed to include the alternative embodiments to the extent permitted by the prior art.